

AD-A094 750

AKRON UNIV OH INST OF POLYMER SCIENCE

F/G 11/1

EFFECT OF INTERFACIAL BONDING ON THE STRENGTH OF ADHESION OF EL--ETC(U)

FEB 81 R J CHANG, A N GENT

N0014-76-C-0408

UNCLASSIFIED

TR-10

NL

1 OF 1  
AD-  
00000000



END  
DATE  
FILMED  
3-81  
DTIC

AD A094750

(12)

OFFICE OF NAVAL RESEARCH

Contract N00014-76-C-0408

Project NR 092-555

**LEVEL II**

Technical Report No. 10

A-4  
750

EFFECT OF INTERFACIAL BONDING ON THE STRENGTH OF ADHESION  
OF ELASTOMERS II. DISSIMILAR ADHERENDS

by

R.-J. Chang and A. N. Gent

Institute of Polymer Science  
The University of Akron  
Akron, Ohio 44325

DTIC  
ECTE  
FEB 09 1981

February, 1981

E

Reproduction in whole or in part is permitted  
for any purpose of the United States Government

Approved for Public Release; Distribution Unlimited

DDC FILE COPY

81 2 09 079

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
Technical Report 10	AD-A094 750	
4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED	
Effect of Interfacial Bonding on the Strength of Adhesion of Elastomers II. Dissimilar Adherends	Technical Report	
7. AUTHOR(s)	6. PERFORMING ORG. REPORT NUMBER	
R.-J./Chang and A. N./Gent	N00014-76-C-0408	
	8. CONTRACT OR GRANT NUMBER(s)	
	NR 092-555	
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Institute of Polymer Science The University of Akron Akron, Ohio 44325		
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE
Office of Naval Research Power Program Arlington, Virginia 22217		February 2, 1981
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES
		15
		15. SECURITY CLASS. (of this report)
		Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)		
Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
Submitted for publication in: Journal of Polymer Science: Polymer Physics Edition		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Adhesion, Bonding, Crosslinking, Elastomers, Fracture, Interface, Strength		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
Two elastomer layers, differing either in initial degree of crosslinking or in chemical reactivity, were bonded together by a free-radical crosslinking process. The elastomers employed were polybutadiene (BR) and an ethylene-propylene copolymer (EPR), differing in the efficiency of crosslinking by dicumyl peroxide by a factor of about 20. When a fully-crosslinked sheet of either elastomer was pressed into contact with a partially-crosslinked		

DD FORM 1473  
1 JAN 73

EDITION OF 1 NOV 65 IS OBSOLETE  
S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Accession For  
ATIS GRAB  
DTE T  
UNRECORDED  
C-10

FBI  
JAN 1968

A

## Introduction

A previous study was concerned with the self-adhesion of elastomer layers bonded together by covalent crosslinks (1). Two identical partially-crosslinked elastomer sheets were brought together and chemically interlinked by taking the crosslinking process to completion. The degree of interlinking was inferred from the increase in crosslink density of the two layers during the second stage of crosslinking, carried out while the layers were in intimate contact. For these symmetrical specimens a direct proportionality was found to hold between the threshold strength of adhesion, i.e., the work of separation per unit of interfacial area measured at low rates of separation and at high temperatures, and the inferred degree of interfacial interlinking.

Experiments have now been carried out on unsymmetrical specimens, in which the two elastomer layers to be bonded together differ either in initial degree of crosslinking or in chemical reactivity. The results are reported here and compared with those obtained previously for symmetrical specimens prepared from the same elastomers.

## Experimental Details

Two types of unsymmetrical joint were prepared. The first consisted of a fully-crosslinked sheet of one

elastomer bonded to a partially-crosslinked sheet of the same elastomer by pressing them together and completing the crosslinking process. This procedure is shown schematically in Figure 1a. A method for estimating the amount of interlinking of the two sheets is outlined in the following section of the paper.

The second type of unsymmetrical joint is shown schematically in Figure 1b. In this case different elastomers were employed for the two sheets. Thus, a fully crosslinked sheet of one elastomer; for example, polybutadiene (BR); was bonded to a partially-crosslinked sheet of another elastomer; for example, an ethylene-propylene copolymer (EPR); by pressing them together and completing the crosslinking process. Again, a method for estimating the amount of interlinking developed is presented in the following section.

The elastomers used for preparing test samples were the same as before: an anionically-polymerized polybutadiene (Diene 35 NFA, Firestone Rubber and Latex Company), and an ethylene-propylene copolymer (Vistalon 404, EXXON Chemical Company). They were crosslinked with a free-radical crosslinking agent, dicumyl peroxide, using recipes given previously (1). Flat sheets, about 0.5 mm thick, were prepared by heating for a time  $t_1$  in a heated press at 150°C. The initial degree of crosslinking depended upon the time  $t_1$ . It was determined by measuring the equilibrium degree of swelling of the partially-crosslinked sheets in n-heptane

(BR) or in benzene (EPR), as described before (1). It was characterized by the number  $\underline{\nu}$  of molecular network strands per unit volume, calculated by means of the Flory-Huggins relationship (2).

Peeling experiments were employed to determine the work  $\underline{G}_a$  of separation per unit area of bonded interface. These measurements were made at a relatively high temperature, 100°C, and at a low rate of peel, 0.4  $\mu\text{m/s}$  so that the values obtained will be close to the threshold strengths of adhesion when contributions from viscoelastic effects in the peeling layers are absent (1). They have been taken here as the threshold strengths  $\underline{G}_0$ .

#### Estimation of the amount of interfacial bonding

##### (i) Different degrees of initial crosslinking.

Let us assume that one layer has been crosslinked fully, so that all of the crosslinking agent with <sup>in</sup> it has been used up. The corresponding density of network strands is denoted  $\underline{\nu}_f$ . The other layer has been partially crosslinked initially and has a strand density of  $\underline{\nu}_1$  before the two layers are brought into contact.

It is now assumed that some diffusion of the unreacted crosslinking agent takes place while the two sheets are being crosslinked in contact. As a result of this diffusion, the contacting region of the <sup>initially</sup> fully-crosslinked layer undergoes additional crosslinking by an amount  $\underline{\nu}_e$ , so that it reaches a final degree of crosslinking of  $\underline{\nu}_f + \underline{\nu}_e$ .

Meanwhile the other layer will crosslink to a lesser extent than it would have otherwise done, because of the loss of crosslinking agent. It will, therefore, reach a final level of crosslinking of  $\underline{v_f - v_e}$  in the region near the interface.

Thus, the interface will separate two regions of elastomer that were initially crosslinked to levels  $\underline{v_f}$  and  $\underline{v_1}$ , and are ultimately crosslinked to levels  $\underline{v_f + v_e}$  and  $\underline{v_f - v_e}$ . They have, therefore, undergone different amounts of additional crosslinking whilst in contact;  $\underline{v_e}$  and  $\underline{v_f - v_1 - v_e}$ , respectively.

The degree of interlinking of the two layers is best represented by the mean of these two values, i.e., by the average extent of additional crosslinking in the two contacting layers. Thus,

$$\overline{\Delta v} = (v_f - v_1)/2. \quad (1)$$

It should be noted that this is one-half of the interlinking developed in a symmetrical system in which each elastomer layer is initially crosslinked to a level  $\underline{v_1}$ .

(ii) Different elastomer layers.

Again, it is assumed that one layer has been fully crosslinked initially. The initial levels of crosslinking are thus represented by  $\underline{v_{f2}}$ , corresponding to the equilibrium value of  $\underline{v}$  for elastomer 2, and  $\underline{v_1}$ , the initial value for elastomer 1. As a result of diffusion of the crosslinking agent from the first layer into the second during the interlinking stage, the final level of crosslinking



attained by elastomer 1 will be lower than if it were crosslinked alone. It is denoted  $v_{f_1} - v_e$ , where  $v_e$  denotes the density of network chains that are lost to elastomer 1 in the vicinity of the interface because of migration of crosslinking agent into elastomer 2.

In the present instance it is necessary to take into account possible differences in efficiency of crosslinking of the two elastomers. The amount of crosslinking agent that creates  $v_e$  crosslinks in elastomer 1 will create a different number, say  $\alpha v_e$  crosslinks, in elastomer 2, where  $\alpha$  denotes the relative efficiency of crosslinking in elastomer 2 compared to elastomer 1. Then the final level of crosslinking for elastomer 2 becomes  $v_{f_2} + \alpha v_e$ .

The two layers have <sup>now</sup> undergone the following changes in crosslinking whilst in contact:  $v_{f_1} - v_1 - v_e$  and  $\alpha v_e$ . The mean value  $\Delta v$  is, therefore, given by

$$2 \Delta v = (v_{f_1} - v_1) + (\alpha - 1)v_e. \quad (2)$$

$\Delta v$  provides an estimate of the degree of interlinking. It can be greater or less than the amount of interlinking developed with layers of the same elastomer, given by equation (1), depending upon the value of  $(\alpha - 1)$ . If  $\alpha$  is greater than 1, then the degree of interlinking is enhanced, whereas, if  $\alpha$  is less than 1, the degree of interlinking is reduced, in comparison with layers of

the same elastomer subjected to the same bonding conditions.

The efficiencies of crosslinking for BR and EPR are apparently quite different. We note that whereas about 0.1 - 0.2 per cent of dicumyl peroxide is sufficient to crosslink BR adequately, 2.7 per cent is required to crosslink EPR to a similar degree. Thus, if a layer of BR represents elastomer 1, i.e., is fully-crosslinked initially, and EPR represents elastomer 2, then the parameter  $\alpha$  may be estimated to be in the range 13 - 27, much greater than unity. On the other hand, if an EPR layer is fully-crosslinked initially, and is then bonded to a partially-crosslinked layer of BR, then the corresponding value of  $\alpha$  becomes  $1/13 - 1/27$ , much smaller than unity. In the former case a higher degree of interlinking would be expected from equation (2), and in the latter case a much lower degree of interlinking, than for layers of the same elastomer. These conclusions have been examined experimentally, as described in the following section.

#### Measurements of the strength of adhesion

- (i) Bonding a partially-crosslinked BR layer to a fully-crosslinked BR layer.

Experimentally-determined values of the work  $G_o$  of separation per unit area of bonded interface, are plotted in Figure 2 against the degree of interlinking

$\Delta v = v_f - v_1$  that would have occurred in a symmetrical system of two partially-crosslinked BR layers.

Experimental results obtained previously with symmetrical specimens are plotted as a full line in Figure 2 for comparison. The present values for  $G_o$ , represented by open circles in the figure, are seen to be approximately proportional to  $\Delta v$  but considerably smaller than before, corresponding to degrees of interlinking of about 70% of  $\Delta v$ . Equation (1) predicts that the effective interlinking would be 50% of  $\Delta v$ . Thus, the experimentally-measured strengths of adhesion are qualitatively in accord with the theoretical predictions, but somewhat higher than expected.

(ii) Bonding a partially-crosslinked EPR layer to a fully-crosslinked EPR layer.

Similar experiments were carried out with EPR layers. The results for  $G_o$  are represented in Figure 3 by open circles. They are compared there with results obtained previously for symmetrical EPR specimens. Again, values of the work  $G_o$  of separation are roughly proportional to the degree of interlinking  $\Delta v$  for corresponding symmetrical specimens, but smaller, as if the actual interlinking was only about 70% of  $\Delta v$ . Thus, as for BR layers, the experimental results for  $G_o$  are qualitatively in accord with the simple theory given in section 3 but somewhat larger.

(iii) Bonding an EPR layer to a BR layer, and vice versa.

Experiments were first carried out with fully-crosslinked sheets of EPR that were pressed into contact with partially-crosslinked sheets of BR and then the crosslinking was taken to completion. Measured values of the detachment energy  $G_o$  are plotted as triangles in Figure 2 against the degree of interlinking  $\Delta v$  that would have occurred using two partially-crosslinked sheets of BR. The strength of adhesion increased linearly with the degree of interlinking  $\Delta v$  but at any level of interlinking the values of  $G_o$  were much smaller than for a symmetrical testpiece with two BR layers. They corresponded roughly to levels of interlinking of only about 40% of  $\Delta v$ , or about one-half of the value of  $\Delta v$  inferred when a BR layer was bonded to a fully-crosslinked BR layer. In the EPR/BR system the parameter  $\alpha$ , representing the relative efficiencies of crosslinking in EPR and BR, is quite small, certainly less than unity and probably less than 0.1. Equation (2) then predicts a low level of interlinking in comparison with the two BR layers. Thus, the experimental results are in good qualitative agreement with theoretical predictions.

When a partially-crosslinked layer of EPR was joined to a fully-crosslinked layer of BR by completing the crosslinking reaction with the two layers in contact, then the strength of adhesion was found to be relatively high. Values of  $G_0$  are plotted in Figure 3 against the degree of interlinking that would have occurred with two partially-crosslinked EPR layers. The present experimental results, represented by triangles, are seen to be quite close to the linear relation obtained previously for symmetrical specimens made by joining two partially-crosslinked EPR layers. Thus, the degree of chemical interlinking may be inferred to be similar also. This high level of interlinking is also consistent with equation (2), recognizing that the parameter  $\alpha$ , denoting the relative crosslinking efficiencies of the two elastomers, is now much greater than unity. In both cases, therefore, the measured strengths of adhesion for dissimilar elastomers are in good qualitative agreement with the predictions of a simple theory for the degree of chemical interlinking. The threshold strength appears to be directly proportional to the degree of interlinking.

### Discussion and conclusions

The experimental systems used in this work represent models for the covulcanization of incompatible elastomers, either in the form of compounds when the elastomers are mixed together in a finely-divided state, or in structures where two elastomer layers are plied together (as in tire manufacture). They might also be regarded as general models of thermosetting adhesives when some reaction takes place across the interface during gelation or setting. In all of the cases studied, whether the layers to be joined together consisted of the same elastomer crosslinked to different degrees or of different elastomers with different reactivity, a general proportionality appears to hold between the mechanical strength of the joint, determined under threshold conditions, and the amount of chemical interlinking existing between the adhering layers. For the simple systems examined here, a method has been proposed for estimating the degree of interlinking from the course of the homogeneous crosslinking or gelation process within an isolated layer. This theory appears to be qualitatively correct, predicting the overall character of the results and the approximate magnitudes. Indeed, in view of the approximations made in developing the theory, the general level of agreement for widely-different systems can be regarded as quite satisfactory.

References

1. R.J. Chang and A.N. Gent, preceding paper.
2. L.R.G. Treloar, "The Physics of Rubberlike Elasticity"  
2nd. ed., Oxford University Press, London, 1968,  
p. 136.

Figure Legends

Figure 1. Examples of interlinking reactions between dissimilar adherends.

- (a) A partially-crosslinked sheet of EPR is crosslinked to completion in contact with a fully-crosslinked sheet of EPR.
- (b) A partially-crosslinked sheet of EPR is crosslinked to completion in contact with a fully-crosslinked sheet of BR.

Figure 2. Detachment energy  $G_0$  for partially-crosslinked BR layers subsequently interlinked:

- (a) to each other (full curve, taken from reference 1),
- (b) to fully-crosslinked BR layers (O),
- (c) to fully-crosslinked EPR layers ( $\Delta$ ).

Figure 3. Detachment energy  $G_0$  for partially-crosslinked EPR layers subsequently interlinked:

- (a) to each other (full curve, taken from reference 1),
- (b) to fully-crosslinked EPR layers (O),
- (c) to fully-crosslinked BR layers ( $\Delta$ ).



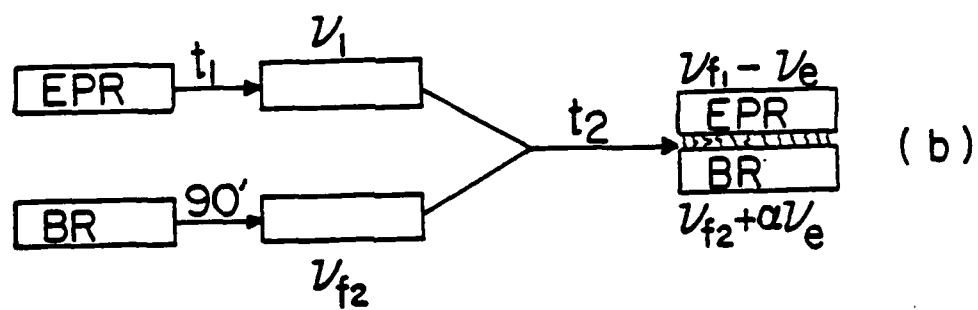
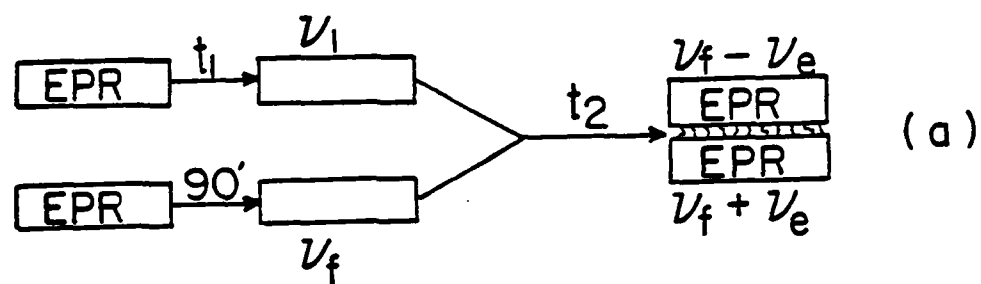
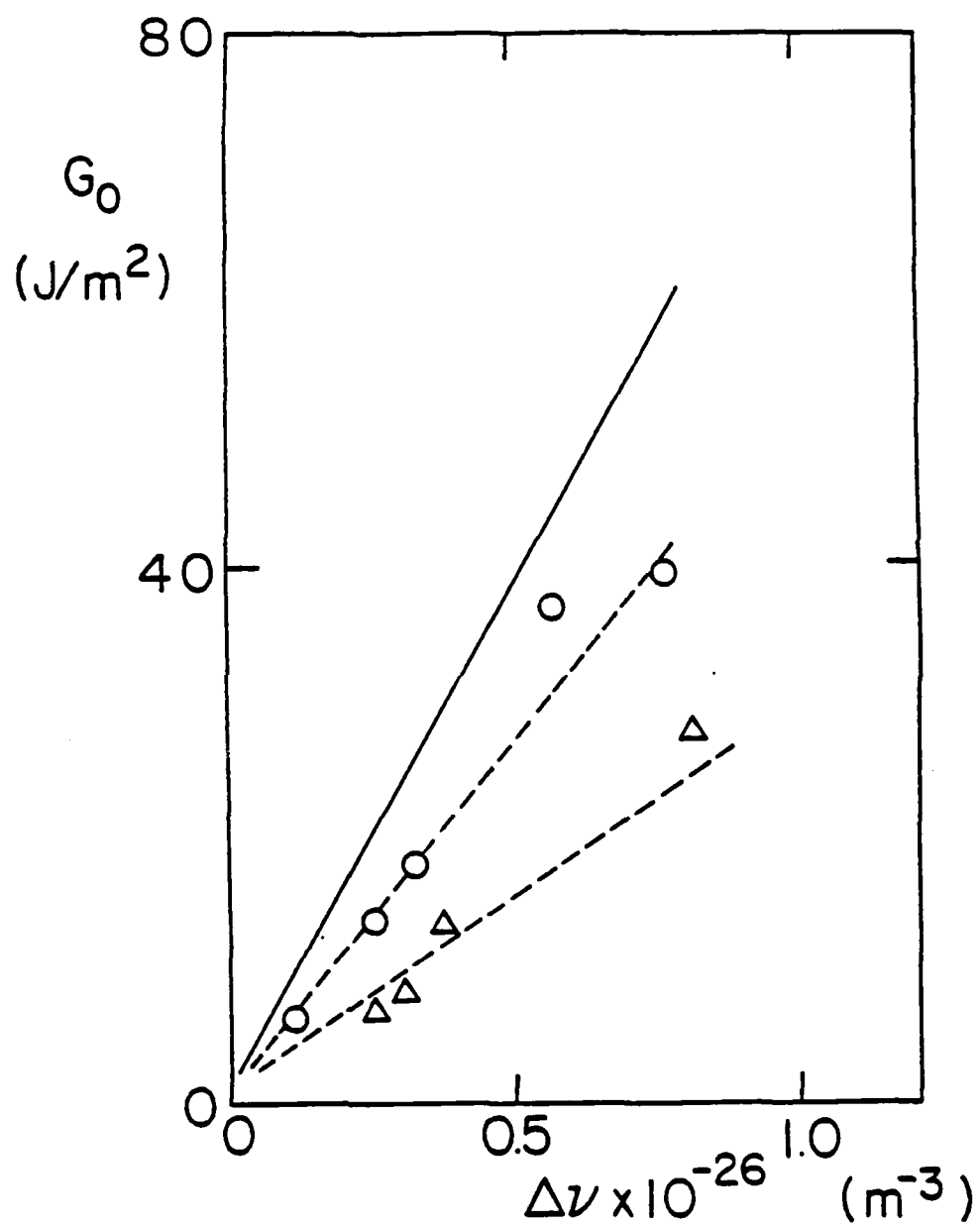
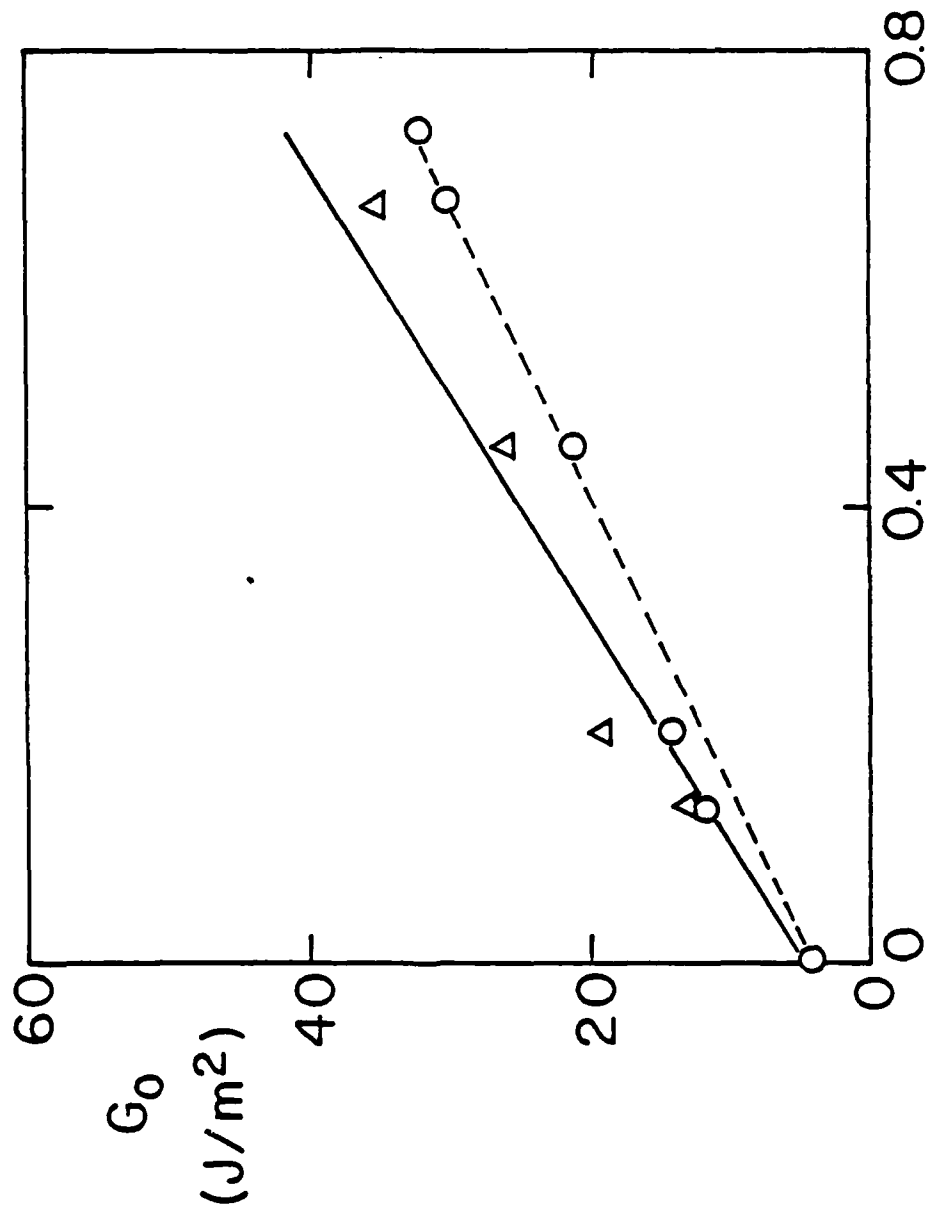


FIGURE 1

FIGURE 2



$\Delta\nu \times 10^{-26}$  (m<sup>-3</sup>)

FIGURE 3

ENERGETIC MATERIALS RESEARCHDISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
Assistant Secretary of the Navy (R, E, and S) Attn: Dr. R.E. Reichenbach Room 5E787 Pentagon Washington, DC 20350	1	AFATL Eglin AFB, FL 32542 Attn: Dr. Otto K. Heiney	1
Office of Naval Research Code 473 Arlington, VA 22217 Attn: Dr. R. Miller	10	AFRPL Code PACC Edwards AFB, CA 93523 Attn: Mr. W. C. Andrepont	1
Office of Naval Research Code 2008 Arlington, VA 22217 Attn: Dr. J. Enig	1	AFRPL Code CA Edwards AFB, CA 93523 Attn: Dr. R. R. Weiss	1
Office of Naval Research Code 260 Arlington, VA 22217 Attn: Mr. D. Siegel	1	Code AFRPL MKPA Edwards AFB, CA 93523 Attn: Mr. R. Geisler	1
Office of Naval Research Western Office 1030 East Green Street Pasadena, CA 91106 Attn: Dr. T. Hall	1	Code AFRPL MKPA Edwards AFB, CA 93523 Attn: Dr. F. Roberto	1
Office of Naval Research Eastern Central Regional Office 495 Summer Street Boston, MA 02210 Attn: Dr. L. Peebles Dr. A. Wood	2	AFSC Andrews AFB, Code DLFP Washington, DC 20334 Attn: Mr. Richard Smith	1
Office of Naval Research San Francisco Area Office One Hallidie Plaza Suite 601 San Francisco, CA 94102 Attn: Dr. P. A. Miller	1	Air Force Office of Scientific Research Directorate of Chemical & Atmospheric Sciences Bolling Air Force Base Washington, DC 20332	1
Defense Technical Information Center DTIC-DDA-2 Cameron Station Alexandria, VA 22314	12	Air Force Office of Scientific Research Directorate of Aero- space Sciences Bolling Air Force Base Washington, DC 20332 Attn: Dr. L. H. Caveny	1
		Anal-Syn Lab Inc. P.O. Box 547 Paoli, PA 19301 Attn: Dr. V. J. Keenan	1

DEF.

	<u>No. Copies</u>		<u>No. Copies</u>
Army Ballistic Research Labs Code DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Mr. L. A. Watermeier	1	Hercules Inc. Eglin AFATL/DL DL Eglin AFB, FL 32542 Attn: Dr. Ronald L. Simmons	1
Army Ballistic Research Labs ARRADCOM Code DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Dr. Ingo W. May	1	Hercules Inc. Magna Bacchus Works P.O. Box 98 Magna, UT 84044 Attn: Mr. E. H. DeButts	1
Army Ballistic Research Labs ARRADCOM Code DRDAR-BLT Aberdeen Proving Ground, MD 21005 Attn: Dr. Philip Howe	1	Hercules Inc. Magna Bacchus Works P.O. Box 98 Magna, UT 84044 Attn: Dr. James H. Thacher	1
Army Missile Command Code DRSME-RK Redstone Arsenal, AL 35809 Attn: Dr. R. G. Rhoades Dr. W. W. Wharton	2	HQ US Army Material Development Readiness Command Code DRCDE-DW 5011 Eisenhower Avenue Room 8N42 Alexandria, VA 22333 Attn: Mr. S. R. Matos	1
Atlantic Research Corp. 5390 Cherokee Avenue Alexandria, VA 22314 Attn: Dr. C. B. Henderson	1	Johns Hopkins University APL Chemical Propulsion Information Agency Johns Hopkins Road Laurel, MD 20810 Attn: Mr Theodore M. Gilliland	1
Ballistic Missile Defense Advanced Technology Center P.O. Box 1500 Huntsville, AL 35807 Attn: Dr. David C. Sayles	1	Lawrence Livermore Laboratory University of California Livermore, CA 94550 Attn: Dr. M. Finger	1
Ballistic Research Laboratory USA ARRADCOM DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Dr. A. W. Barrows	1	Lawrence Livermore Laboratory University of California Livermore, CA 94550 Attn: Dr. R. McGuire	1
Hercules Inc. Cumberland Aerospace Division Allegany Ballistics Lab P.O. Box 210 Cumberland, MD 21502 Attn: Dr. Rocco Musso	2	Lockheed Missiles and Space Co. P.O. Box 504 Sunnyvale, CA 94088 Attn: Dr. Jack Linsk Org. 83-10 Bldg. 154	1

DEF.

	<u>No. Copies</u>		<u>No. Copies</u>
Lockheed Missile & Space Co. 3251 Hanover Street Palo Alto, CA 94304 Attn: Dr. H. P. Marshall Dept. 52-35	1	Naval Research Lab Code 6100 Washington, DC 20375	1
Los Alamos Scientific Lab P.O. Box 1663 Los Alamos, NM 87545 Attn: Dr. R. Rogers, WX-2	1	Naval Sea Systems Command Washington, DC 20362 Attn: Mr. G. Edwards, Code 62R3 Mr. J. Murrin, Code 62R2 Mr. W. Blaine, Code 62R	1
Los Alamos Scientific Lab P.O. Box 1663 Los Alamos, NM 87545 Attn: Dr. B. Craig, M Division	1	Naval Sea Systems Command Washington, DC 20362 Attn: Mr. R. Beauregard SEA 64E	1
Naval Air Systems Command Code 330 Washington, DC 20360 Attn: Mr. R. Heitkotter Mr. R. Brown	1	Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. H. G. Adolph	1
Naval Air Systems Command Code 310 Washington, DC 20360 Attn: Dr. H. Mueller Dr. H. Rosenwasser	1	Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910 Attn: Dr. R. Bernecker	1
Naval Explosive Ordnance Disposal Facility Indian Head, MD 20640 Attn: Lionel Dickinson Code D	1	Naval Surface Weapons Center Code R10 White Oak, Silver Spring, MD 20910 Attn: Dr. S. J. Jacobs	1
Naval Ordnance Station Code 5034 Indian Head, MD 20640 Attn: Mr. S. Mitchell	1	Naval Surface Weapons Center Code R17 White Oak, Silver Spring, MD 20910 Attn: Dr. M. J. Kamlet	1
Naval Ordnance Station Code PM4 Indian Head, MD 20640 Attn: Mr. C. L. Adams	1	Naval Surface Weapons Center Code R04 White Oak, Silver Spring, MD 20910 Attn: Dr. D. J. Pastine	1
Dean of Research Naval Postgraduate School Monterey, CA 93940 Attn: Dr. William Tolles	1	Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910 Attn: Dr. E. Zimet	1
Naval Research Lab Code 6510 Washington, DC 20375 Attn: Dr. J. Schnur	1		

DEF.

	<u>No. Copies</u>		<u>No. Copies</u>
Naval Surface Weapons Center Code R101 Indian Head, MD 20640 Attn: Mr. G. L. MacKenzie	1	Naval Weapons Center Code 388 China Lake, CA 93555 Attn: D. R. Derr	1
Naval Surface Weapons Center Code R17 Indian Head, MD 20640 Attn: Dr. H. Haiss	1	Naval Weapons Center Code 388 China Lake, CA 93555 Attn: Dr. R. Reed Jr.	1
Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. K. F. Mueller	1	Naval Weapons Center Code 385 China Lake, CA 93555 Attn: Dr. A. Nielsen	1
Naval Surface Weapons Center Code R16 Indian Head, MD 20640 Attn: Dr. T. D. Austin	1	Naval Weapons Center Code 3858 China Lake, CA 93555 Attn: Mr. E. Martin	1
Naval Surface Weapons Center Code R122 White Oak, Silver Spring, MD 20910 Attn: Mr. L. Roslund	1	Naval Weapons Center China Lake, CA 93555 Attn: Mr. R. McCarten	1
Naval Surface Weapons Center Code R121 White Oak, Silver Spring, MD 20910 Attn: Mr. M. Stosz	1	Naval Weapons Support Center Code 5042 Crane, Indiana 47522 Attn: Dr. B. Douda	1
Naval Weapons Center Code 3853 China Lake, CA 93555 Attn: Dr. R. Atkins	1	Rohm and Haas Company 723-A Arcadia Circle Huntsville, Alabama 35801 Attn: Dr. H. Shuey	1
Naval Weapons Center Code 3205 China Lake, CA 93555 Attn: Dr. L. Smith	1	Strategic Systems Project Office Dept. of the Navy Room 901 Washington, DC 20376 Attn: Dr. J. F. Kincaid	1
Naval Weapons Center Code 3205 China Lake, CA 93555 Attn: Dr. C. Thelen	1	Strategic Systems Project Office Dept. of the Navy Room 1048 Washington, DC 20376 Attn: Mr. E. L. Throckmorton Mr. R. Kinert	2
Naval Weapons Center Code 385 China Lake, CA 93555 Attn: Dr. A. Amster	1	Thiokol Chemical Corp. Brigham City Wasatch Division Brigham City, UT 84302 Attn: Dr. G. Thompson	1

DEF.

	<u>No. Copies</u>		<u>No. Copies</u>
USA ARRADCOM DRDAR-LCE Dover, NJ 07801 Attn: Dr. R. F. Walker	1	Georgia Institute of Technology Office of Research Administration Atlanta, Georgia 30332 Attn: Professor Edward Price	1
USA ARRADCOM DRDAR-LCE Dover, NJ 07801 Attn: Dr. N. Slagg	1	Univ. of Utah Dept. of Mech. & Industrial Engineering MEB 3008 Salt Lake City, Utah 84112 Attn: Dr. Stephen Swanson	1
U.S. Army Research Office Chemistry Division P.O. Box 12211 Research Triangle Park, NC 27709	1	Space Sciences, Inc. 135 Maple Avenue Monrovia, CA 91016 Attn: Dr. M. Farber	1
Institute of Polymer Science University of Akron Akron, OH 44325 Attn: Professor Alan N. Gent	1	Washington State University Dept. of Physics Pullman, WA 99163 Attn: Professor G.D. Duval	1
SRI International 333 Ravenswood Avenue Menlo Park, CA 94025 Attn: Dr. Y.M. Gupta	1	Univ. of Maryland Department of Mechanical Eng. College Park, MD 20742 Attn: Professor R.W. Armstrong	1
Graduate Aeronautical Lab. California Institute of Technology Pasadena, CA 91125 Attn: Professor W.G. Knauss	1	The Catholic University of America Physics Department 520 Michigan Ave., N.E. Washington, D.C. 20017 Attn: Professor T. Litovitz	1
Pennsylvania State University Dept. of Mechanical Engineering University Park, PA 16802 Attn: Professor Kenneth Kuo	1	Sandia Laboratories Division 2513 P.O. Box 5800 Albuquerque, N.M. 87185 Attn: Dr. S. Sheffield	1
Office of Naval Research 800 N. Quincy St. Arlington, VA 22217 Attn: Dr. G. Neece Code 472	1	IBM Research Lab. K42.282 San Jose, CA 95193 Attn: Dr. Thor L. Smith	1
Thiokol Corp. Huntsville Huntsville Div. Huntsville, AL 35807 Attn: Mr. J.D. Byrd	1	California Institute of Tech. Dept. of Chemical Engineering Pasadena, CA 91125 Attn: Professor N.W. Tschoegl	1
Washington State University Dept. of Physics Pullman, WA 99163 Attn: Prof. T. Dickinson	1	Northwestern University Dept. of Civil Engineering Evanston, IL 60201 Attn: Professor J.D. Achenbach	1
University of California Dept. of Chemistry 405 Hilgard Avenue Los Angeles, CA 90024 Attn: Prof. M.F. Nicol	1	Office of Naval Research Structural Mechanics Program Arlington, VA 22217 Attn: Dr. N.L. Basdekas, Code 474	1



DEF.

No. Copies

University of California 1  
Berkeley, CA 94720  
Attn: Prof. A.G. Evans

Texas A&M Univ. 1  
Dept. of Civil Engineering  
College Station, TX 77843  
Attn: Professor Richard A. Schapery

SRI International 1  
333 Ravenswood Ave.  
Menlo Park, CA 94025  
Attn: Mr. M. Hill

Los Alamos Scientific Laboratory 1  
Los Alamos, NM 87545  
Attn: Dr. J.M. Walsh

Rockwell International 1  
12214 Lakewood Blvd.  
Downey, California 90241  
Attn: H. M. Clancy, Mail Stop AB70

DATE  
FILMED  
— 8